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ANGULAR MOMENTUM DEPENDENCE OF THE GDR OBSERVABLES OF $A = 170$ NUCLEI AT FINITE TEMPERATURE*

M. MATTIUZZI, A. BRACCO, F. CAMERA, B. MILLION

Dipartimento di Fisica, Università di Milano
Via Celoria 16, I-20133 Milano, Italy

J.J. GAARDHØJE, A. MAJ**, T. TVETER, Z. ŻELAZNY

The Niels Bohr Institute, University of Copenhagen
Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark

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A recent exclusive measurement of the γ decay of the Giant Dipole Resonance in hot ^{176}W nuclei is here presented. For the first time the two observables, strength function and angular anisotropy coefficient $a_2(E_\gamma)$, were measured at a temperature of $T = 1.5$ MeV at different values of the angular momentum of the compound nucleus, spanning the interval from 35 up to 55 $\hbar$. At this temperature shell effects are almost completely washed out and this nucleus shows deformations that are smaller than the ones at zero temperature. The $a_2(E_\gamma)$ and GDR width data are very well reproduced in all the selected spin windows, by predictions based on thermal shape and orientation fluctuations and using the collisional damping width at zero temperature.

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1. Introduction

Studies of the giant dipole resonance (GDR) in hot rotating nuclei offer the possibility to learn about thermal fluctuations of the nuclear shape

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** Permanent address: Niewodniczański Institute of Nuclear Physics, Radzikowskiego 152, 31-342 Kraków, Poland.

and orientation and about the collisional damping at finite temperature (T) and rotational frequency (ω). In fact, the important damping mechanisms giving rise to the GDR width are the relaxation of the simple collective mode into more complicated states (collisional damping) and the spreading of the dipole frequency due to the coupling to the different quadrupole deformations of the shape ensemble characterizing a nucleus at finite T and ω. Recently, exclusive measurements of the strength function and of the angular distributions of the high energy γ rays as a function of angular momentum were made for ^{110,109}Sn nuclei at approximately $T \approx 1.8$ MeV [1]. They showed that the collisional damping width does not depend on T and ω (Ref. [1] and lecture of Bracco at this school). Tin nuclei are characterized by spherical shapes at $T = 0$ and $\omega = 0$, and become oblate at $T \neq 0$ under the stress of centrifugal and Coriolis forces. In order to understand better the role of deformation in the GDR response, it is very important to study with the same detail nuclei of other mass region. New measurements of the strength function and angular distribution as a function of angular momentum ($35 - 55\hbar$) at $T = 1.5$ MeV for the ^{176}W nucleus are reported here. This nucleus has a prolate shape ($\beta = 0.3$) at $T = 0$ and $\omega = 0$ and is expected to become oblate at $T \approx 1.5$ MeV with a smaller deformation that those of Sn nuclei at the same excitation energy and angular momentum. The present data are compared to predictions based on thermal shape and orientation fluctuations in the adiabatic limit. It is possible to conclude that in this case also the collisional damping width Γ_0 does not depend on T and ω .

2. Measurements

The experiment was performed at the Niels Bohr Institute using the Tandem + Booster configuration at Risø, Roskilde, Denmark. A 147 MeV ^{28}Si beam bombarded a ^{148}Nd target leading to ^{176}W with an average momentum of 38 $\hbar$ and an excitation energy E^* of about 70 MeV. The detection system was HECTOR [2, 3] in its upgraded configuration. The multi-detector array consists of 8 large volume BaF_2 scintillators (placed at four angles with respect to the beam axis) for measuring the energy of the high energy photons and of a multiplicity filter of 38 small BaF_2 detectors for measuring the coincidence fold of the low energy γ rays. In order to select the events coming from fusion reactions we put a gate on the fold measured with the multiplicity filter. In the analysis we accepted only the events in coincidence with fold $F \geq 9$, since the events associated with lower values were clearly contaminated by non fusion reactions (see Fig. 1).

With the latest implementation of the HECTOR detector array containing two PPAC detectors for the recoils we have confirmed that indeed

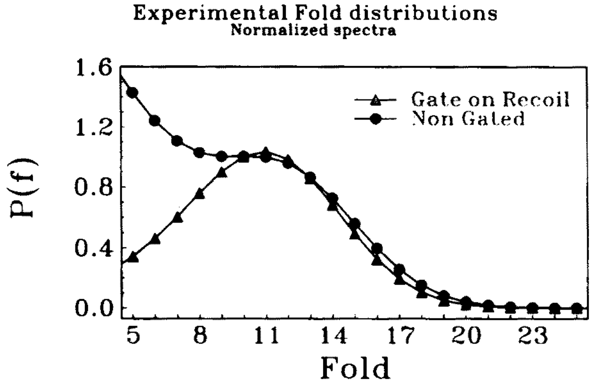

Fig. 1. Experimental fold distributions measured in the multiplicity filter in a heavy ion reaction ^{58}Ni $+^{48}$Ti at 261 MeV. The circles represent the fold distributions without any gate on the recoiling mass nuclei, while the triangles represent the fold distribution with a gate on the recoil time of flight of heavy residues measured with PPAC detectors.

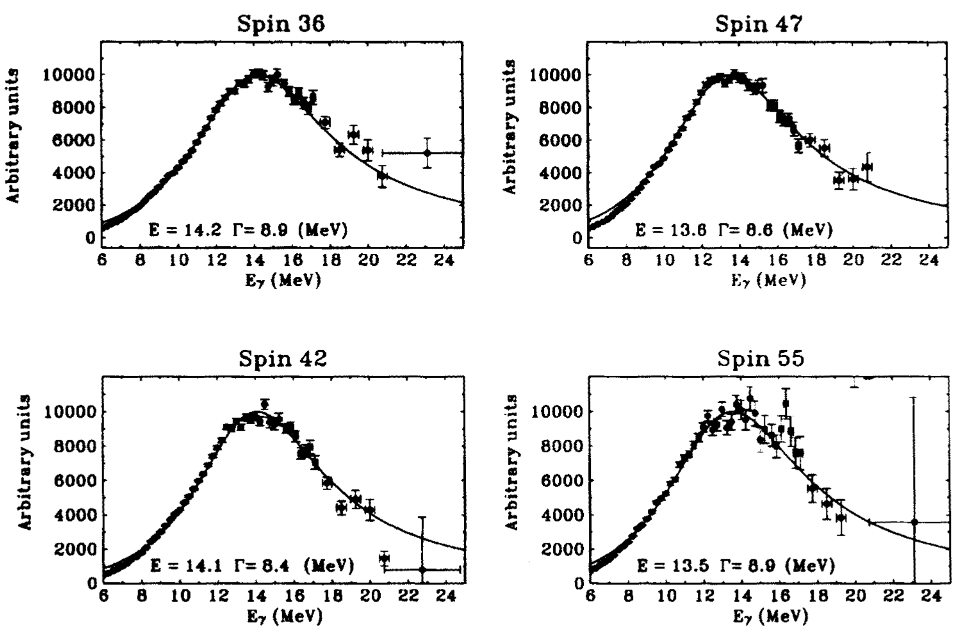

Fig. 2. Strength function at temperature $T = 1.42$ MeV for the ^{176}W nucleus at four different angular momenta windows centered around the average value reported above each panel. Full drawn lines display the Lorentzian obtained from the best fitting statistical model calculations. The GDR energies E and widths Γ are given in the bottom part of each panel.

the multiplicity spectrum at $F < 9$ contains large contributions from non fusion reactions (see figure 1). With the multiplicity filter we have selected four different multiplicity windows and with a standard calibration technique [4, 5] we have estimated the corresponding spin distributions. The $a_2(E_\gamma)$ were obtained fitting the spectra measured at different angles relative to beam axis with the function $N(E_\gamma, \theta) = N_0(E_\gamma)[1+a_2(E_\gamma)P_2(cos(\theta)]$ where $P_2(cos(\theta))$ is the Legendre polynomial. In Figure 2 some spectral data are shown in a linearized form, namely the quantity $f(E_\gamma) \times Y_\gamma^{\mathrm{exp}}(E_\gamma)/Y_\gamma^{\mathrm{calc}}(E_\gamma)$ is plotted to emphasize the details of the high energy γ ray spectrum in the GDR region. The quantity $Y_\gamma^{\mathrm{exp}}(E_\gamma)$ is the measured spectrum while $Y_\gamma^{\mathrm{calc}}(E_\gamma)$ is the spectrum calculated with the statistical model, and $f(E_\gamma)$ is the lorentzian function which gives the best fit to the data. In the statistical model analysis, the energy E_{GDR} and the width Γ_{GDR} of the GDR were left free to vary until the χ^2 was minimized. It was assumed that 100 % of the EWSR is exhausted by the GDR, E_{GDR} and Γ_{GDR} were kept unchanged for the different steps along the decay cascade of the compound nucleus. The measured spin distributions of the fusion cross section associated to the selected coincidence fold intervals were used. The calculated and measured spectra were normalized in the region E_γ = 9–19 MeV. The statistical model results were folded with the detector response calculated using the GEANT3 [6] libraries.

The width and the angular anisotropy of the high energy γ rays (see Figures 2, 4 and 5) were found to be rather constant with spin, with the exception of the $a_2(E_\gamma)$ that at $< I >= 55$ is larger.

3. Comparison with model predictions

The interpretation of the present results requires calculations of the shape distributions associated to the measured cases. The Boltzmann factor that gives the probability of finding a nucleus at a particular deformation is proportional to $\exp(-F(\beta,\gamma)/T)$ (see Fig. 3).

The free energy was calculated at constant T and ω, making use of the liquid drop model including shell corrections obtained with the Nilsson–Strutinsky method. The strength function and the $a_2(E_\gamma)$ were calculated in the adiabatic limit by averaging over the GDR line shapes computed at different deformations and weighted with the Boltzmann factor [7]. The results including only shape fluctuations are shown with dashed lines in Figure 4. Note that a constant width independent of angular momentum is also predicted by this model and this constancy reflects the fact that the shape distributions (see Figure 3) are rather similar in all these cases.

In addition, while the GDR width is very well reproduced by the calculations, the $a_2(E_\gamma)$ data are not. Contrary to the strength function, the

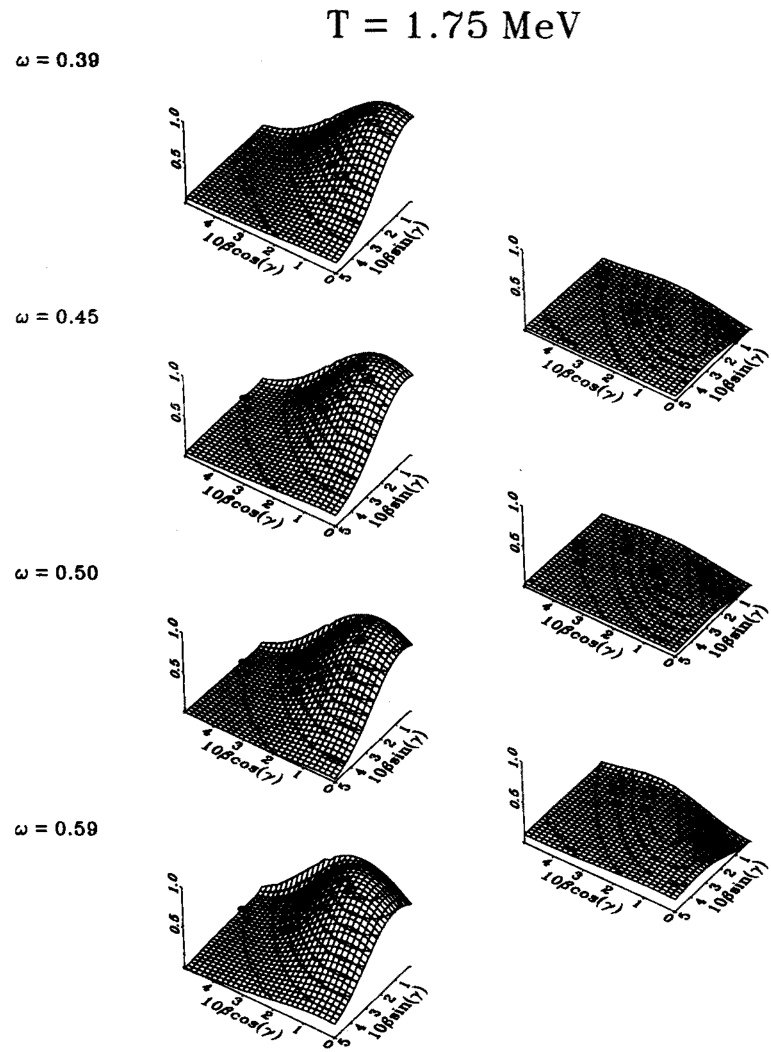

Fig. 3. Three-dimensional representations of the shape probability given by the Boltzmann factor $\exp(-F(T, \omega, \beta, \gamma \ldots))$ where F is the free energy. In the left-hand side, the calculations are shown as a function of the quadrupole deformation parameters β and γ at a constant temperature T and at the four rotational frequencies relative to the average spins of Figures 2 and 3. In the right part of the figure the differences between two consecutive plots of the left-hand side are displayed to emphasize a small and homogeneous difference.

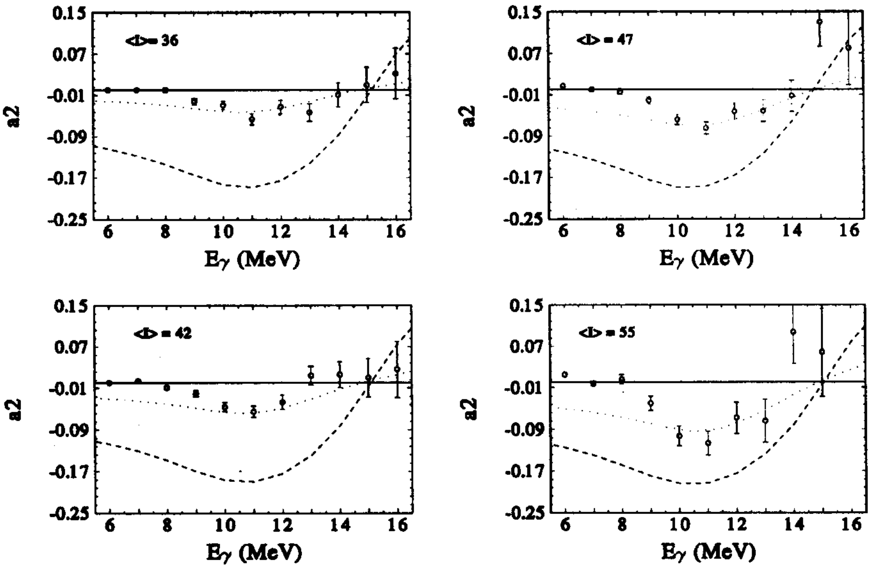

Fig. 4. The $a_2(E_\gamma)$ coefficient as a function of the transition energy of the γ rays emitted by the ^{176}W at excitation energy 70 MeV. The four plots are associated to different angular momenta windows centered at the average value shown in the top left part of each panel. The dashed curves are the results of calculations of shape fluctuations only, whereas the dotted curves show the result of previous calculation including also orientation fluctuations; adiabatic limit was used.

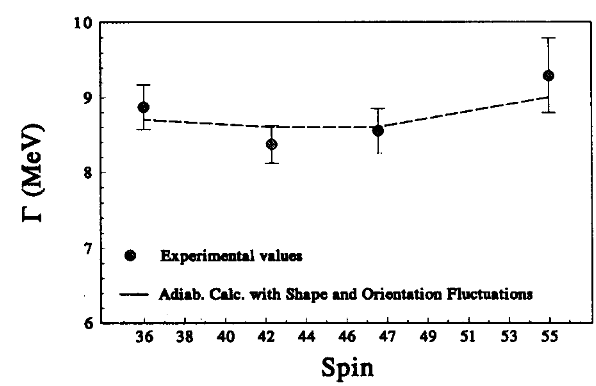

Fig. 5. Measured GDR width Γ as a function of the compound nucleus angular momenta. The experimental values, represented by circles, are obtained with statistical model calculations. The predictions based on the theoretical model including shape and orientation fluctuations are also shown by dashed line.

angular distribution depends on the nuclear orientation and therefore on its fluctuations. Predictions including both shape and orientation fluctuations are shown with dotted line (Fig. 4) and with the dashed line (Fig. 5). In this case the data are well reproduced for the four measured angular momenta. It should be noted that the calculations were made using an intrinsic width (or collisional damping width) equal to the GDR width measured at $T = 0$ and $\omega = 0$.

4. Conclusion

The angular distribution and the strength function of the γ rays emitted by the giant dipole resonance in ^{176}W at $T = 1.42$ MeV have been measured at four average angular momenta selected in the range 35–55 $\hbar$.

A rather constant value of the two observables with spin was found that is well reproduced by calculations including of thermal shape and orientation fluctuations in the adiabatic limit. The good agreement between data and theory demonstrates the important role of shape and orientation fluctuations and that the collisional damping width is independent of temperature and rotational frequency. Since so far only the temperature dependence of the collisional damping was investigated [8], this work should motivate a theoretical effort towards the understanding of collisional damping as a function of rotational frequency at finite temperature.

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